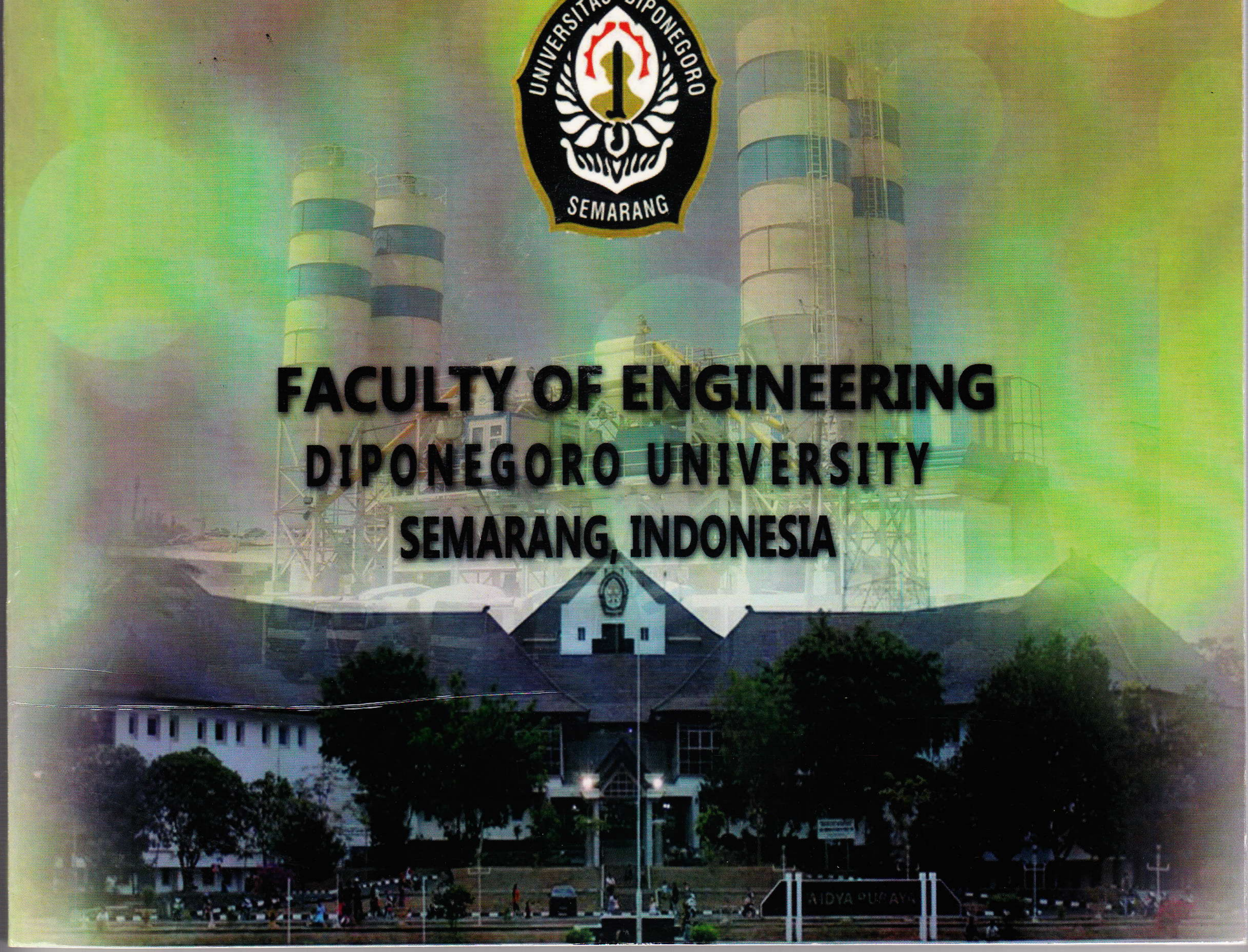
# PROCEEDINGS

## International Seminar on Concrete Technology

# GREEN CONCRETE TECHNOLOGY INNOVATION

*The 56th Dies Natalis of Diponegoro University*
*The 55th Dies Natalis of Faculty of Engineering*
*June 4, 2013*



## FACULTY OF ENGINEERING
## DIPONEGORO UNIVERSITY
## SEMARANG, INDONESIA

Penerbit UNDIP PRESS
SEMARANG 2013

SEMARANG, INDONESIA
NO ISBN : 978-602-097-375-3

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# L-SHAPED STEEL COLLARS: AN ALTERNATIVE EXTERNAL CONFINING RETROFIT FOR IMPROVING DUCTILITY AND STRENGTH OF RECTANGULAR CONCRETE COLUMNS

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## ABSTRACT

Confinement in concrete column has been well known to improve its strength and ductility. Such enhancement is primarily essential when needed to improve the behavior of concrete columns particularly in terms of ductility during the earthquake strike. This advantage is in line with the modern concept of moment-resisting frame which requires ductile structural framing members. Up to present, traditional transverse steel is still used as internal confinement in concrete column. Several researches have been conducted extensively to study the behavior of confined column, both analytically and experimentally. All these studies confirmed that internal confining method significantly improves the strength and ductility of the columns. However, sometimes the existing columns in a building do not satisfy the building code requirements either unintentionally or due to the unawareness of seismic hazards in terms of confinement. Once the column is built and cast, there is no way to revise the lack of transverse steel internally. The only way possible is to retrofit the columns by using external means. High demand of strengthening on existing RC buildings has made external confinement becoming increasingly popular as an alternative external confining retrofit for RC columns. Various types of external confinement have been introduced to increase the strength and ductility of the columns, such as FRP wrap or even the use of steel jacketing. These external confining techniques have been proven to be successful in retrofitting circular concrete columns. Experimental programs as well as confining models for externally confined circular columns have been well developed. It is, however, still uneasy to provide an effective confining stress by external retrofit on square or rectangular concrete column. The non-uniform confining stress on column is due to high stress concentration at column corners. Only a few experimental and analytical studies addressed these issues.The most recent proposed external confinement method is by using the steel collars with hollow square section. This kind of confinement method has been proven to work well as confining system for concrete columns. The strength and particularly the ductility of the columns have been improved significantly. However, it is still too heavy and uneconomical for use as column retrofit. The need of light and economic types of external confining retrofit is urgently required in the country like Indonesia. Thus, an external confining method that is utilizing light L-shape steel section is studied for its capability as an alternative retrofit for rectangular or square concrete columns. This paper is a part of the first phase of a multiyear research project carried out by the authors. In this paper, a proposed alternative external retrofit for improving the ductility and strength of square concrete columns is presented. Eight columns specimens were cast and tested under monotonic compressive loading. A set of L-shaped steel collars have been introduced externally on square concrete columns prior to testing. The results have confirmed that the proposed external confining techniques considerably enhanced the compressive strength and ductility of the column specimens.

**Keywords:** Compressive strength, Ductility, External confinement, Retrofit, Square concrete columns, Steel collars, Stress-strain curves.

## INTRODUCTION

The confinement conventionally provided by traditional transverse reinforcement has been well known to significantly enhance the strength and ductility of RC columns [1-4]. Many analytical and experimental studies conducted to investigate the effects of confinement can be found in literatures [1-30]. Those researches cover circular, rectangular, and square column sections. The loadings on the specimens include axial and combined axial and bending in monotonic and cyclic patterns. It is generally concluded that the affecting variables of confined concrete behavior are the plain concrete compressive strength, volumetric ratio of confinement steel to concrete core, yield strength of confining reinforcement, ratio of area of longitudinal steel around the core perimeter and the resulting tie configuration, and tie spacing. General agreements on the improved stress-strain relationship of confined concrete are the increment of compressive strength, flatter post-peak descending branch of the curve, and increment of ultimate compressive strain (increment of ductility).

Besides the conventional confinement studies, recent research are extended to external confinement approach [5-8]. It is essential to develop such approach due to high demands on concrete columns retrofits. Early studies primarily deal with circular concrete column retrofits. This kind of retrofits has been proven by experiments to be successful. The most recent proposed external confinement method is by using the steel collars with hollow square section. This confinement method has been proven to work well as confining system for concrete columns. The strength and particularly the ductility of the columns have been improved significantly. However, it is still too heavy and uneconomical for use as column retrofit. The need of light and economic types of external confining retrofit is urgently required in the country like Indonesia. Thus, an external confining method that is utilizing light L-shape steel section is studied for its capability as an alternative retrofit for rectangular or square concrete columns. However, for rectangular and square columns, predicting effective confining stress by external retrofit is not a simple task. Similar to internal confinement, the confining stress in this sectional shapes, is not uniform due to stress concentration in the corners. Some experimental and only a few analytical studies are found to address this problems [9-11]. The complexity of external confinement includes failure mechanism, contact behavior between concrete and external confinement elements, and distribution of confining stress in 3D space, which can be totally different to those of conventional stirrups.

This paper is a part of the first phase of a multiyear research project conducted by the authors. Eight columns specimens were cast and tested under monotonic concentric compressive loading. A set of L-shaped steel collars have been introduced externally on square concrete columns prior to testing. The experimental work confirmed the performance of square columns considerably improved by the introduction of this type of external confinement. The results obtained from the experimental test included the axial stress-strain curves as well as the damage patterns. It confirmed that the proposed external confining techniques considerably enhanced the compressive strength and ductility of the column specimens. The research mainly aims to provide a better understanding of the impact of external steel collar confinement on the behavior of concrete columns.

## EXPERIMENTAL SETUP

The strength and ductility enhancement of concrete columns retrofitted by external steel collars was investigated in the study. The proposed steel section used as an alternative external confining retrofit on square concrete columns was that commonly available in the market and economical, i.e. the L-shaped steel section. The sectional dimensions were L40.40.4. The external confinement was implemented on the column specimen by mounting up the L-sections on its four faces with uniform spacing and then fastened the structural bolts at its four corners. The typical perspective illustration of the assembled and exploded views of a typical specimen can be seen in Figures 1 and 2. The column sizes were 600 mm high with 200×200 mm$^2$ square cross section. Both 100-mm bottom and top ends of the column specimens were heavily confined that no damage was expected in these non-test regions. The 400-mm mid-test region was confined with various numbers of external steel collars. A set of rods were also installed within the test regions defining the gauge lengths on each face of the column specimens. Plan and elevation views of the typical specimens are depicted in Figures 3 and 4. The specimens were then tested under monotonic concentric compressive loading as shown in Figure 5.

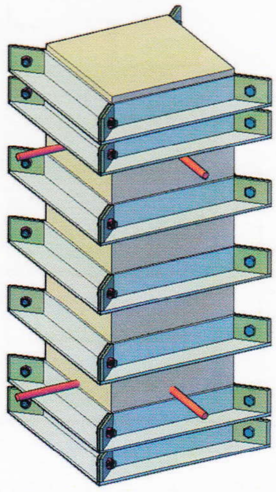

**Figure 1:** Typical Perspective View of Test Specimen (Specimen S03 as an Illustration)

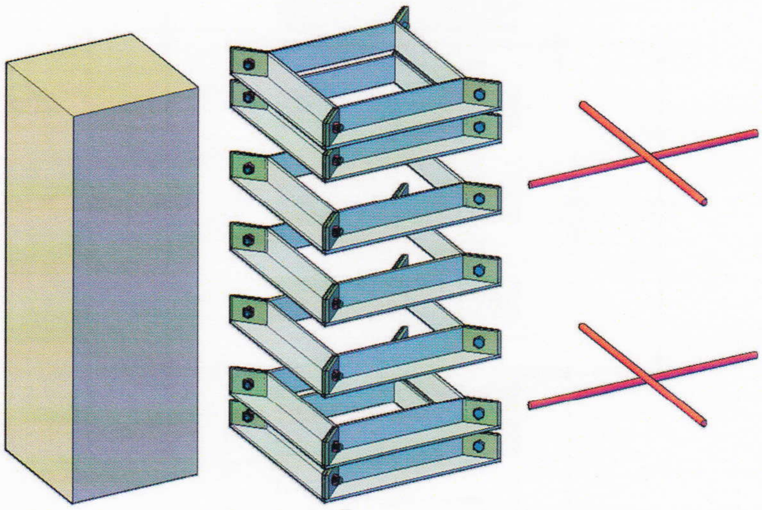

**Figure 2:** Typical Exploded View of Test Specimen (Specimen S03 as an Illustration)

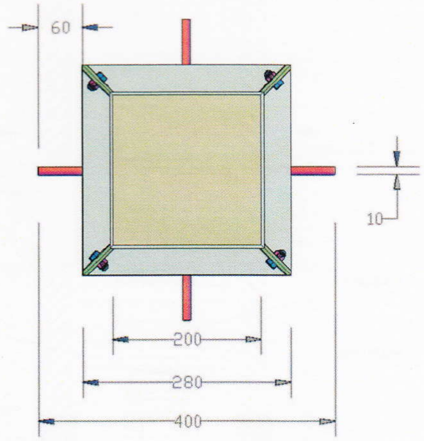


**Figure 3:** Typical Plan View of Test Specimen (Specimen S03 as an Illustration)
Plan View of Test Specimen (Specimen S03 as an Illustration)

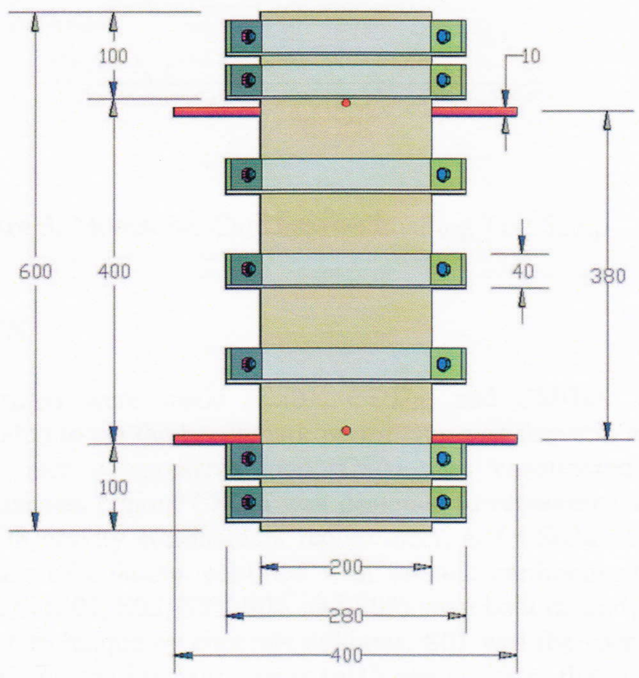


**Figure 4:** Typical Elevation View of Test Specimen (Specimen S03 as an Illustration)

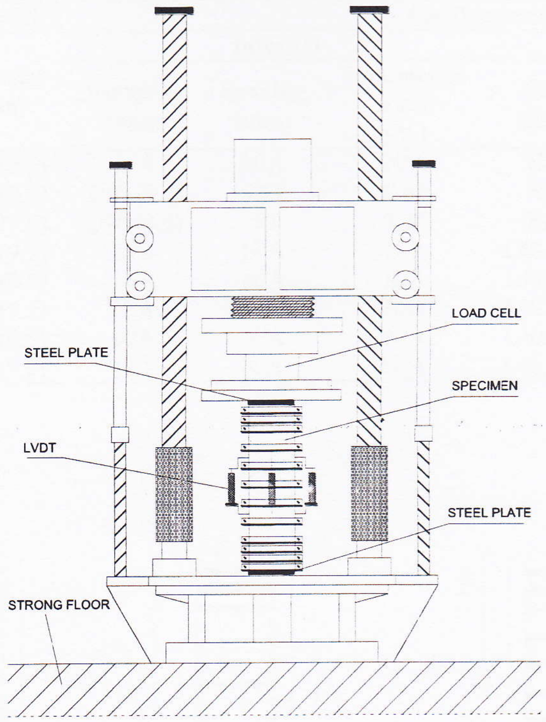


**Figure 5:** Monotonic Compressive Loading Test Setup

## SPECIMEN DESIGN

Three control specimens were made (CS01, CS02a, and CS03a). These control specimens were intended to set the benchmark performance of conventionally confined column specimens under compressive load. CS01 was constructed without any confinement within the test region; CS02a was designed to represent the condition of columns confined with gravity confinement requirement; and CS03a was designed to represent the condition of columns confined with seismic confinement requirement. Five collared specimens (S01, S02, S03, S04, and S05) were built to study the impact of proposed confinement technique on concrete columns. S01 was the specimen with the lowest volumetric ratio of confinement collars (with one collar in the mid-test region), while S05 was the highest (five collars in the mid-test region). The volumetric ratio set for these five specimens, namely S01, S02, S03, S04, and S05, were 3.84, 5.77, 7.68, 9.60, and 11.51 percent, respectively. The volumetric ratio is defined as the volume of a collar with respect to the volume of column determined from the gross cross-sectional area of the column multiplied by the spacing of collars within the mid-test region. Table 1 summarizes the details of reinforcement and confinement of the test specimens. The specimens were equipped with several strain gauges to take the deformation measurement of concrete and steel as shown in Figures 6 to 9. These figures also show the configuration of external steel collars on column specimens S01 to S05.

**Table 1:** Details of Test Specimen's Reinforcement and Confinement

| Column ID | Longitudinal Steel | | Confinement | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | Internal | | | External | | |
| | Number | Diameter (mm) | Diameter (mm) | Spacing (mm) | Volumetric Ratio (%) | Size (mm) | Spacing (mm) | Volumetric Ratio (%) |
| CS01 | 4 | D10 (9.5) | N/A | N/A | N/A | N/A | N/A | N/A |
| CS02a | 4 | D10 (9.5) | D10 (9.5) | 133 | 0.89 | N/A | N/A | N/A |
| CS03a | 4 | D10 (9.5) | D10 (9.5) | 50 | 2.36 | N/A | N/A | N/A |
| S01 | 4 | D10 (9.5) | N/A | N/A | N/A | L40.40.4 | 200 | 3.84 |
| S02 | 4 | D10 (9.5) | N/A | N/A | N/A | L40.40.4 | 133 | 5.77 |
| S03 | 4 | D10 (9.5) | N/A | N/A | N/A | L40.40.4 | 100 | 7.68 |
| S04 | 4 | D10 (9.5) | N/A | N/A | N/A | L40.40.4 | 80 | 9.60 |
| S05 | 4 | D10 (9.5) | N/A | N/A | N/A | L40.40.4 | 67 | 11.51 |

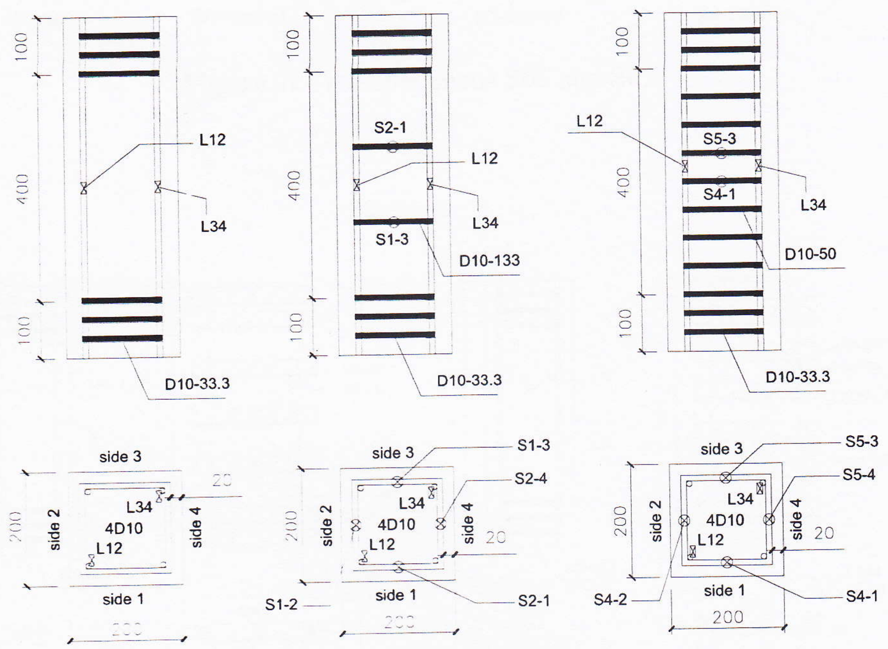


**Figure 6:** Control Specimens CS01, CS02a, and CS03a

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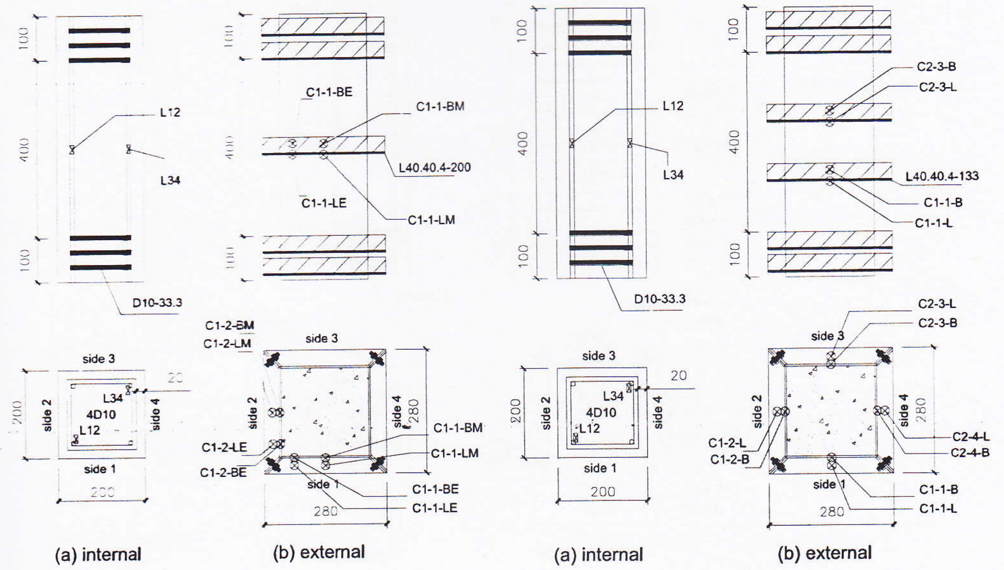



**Figure 7:** Test Specimens S01 and S02

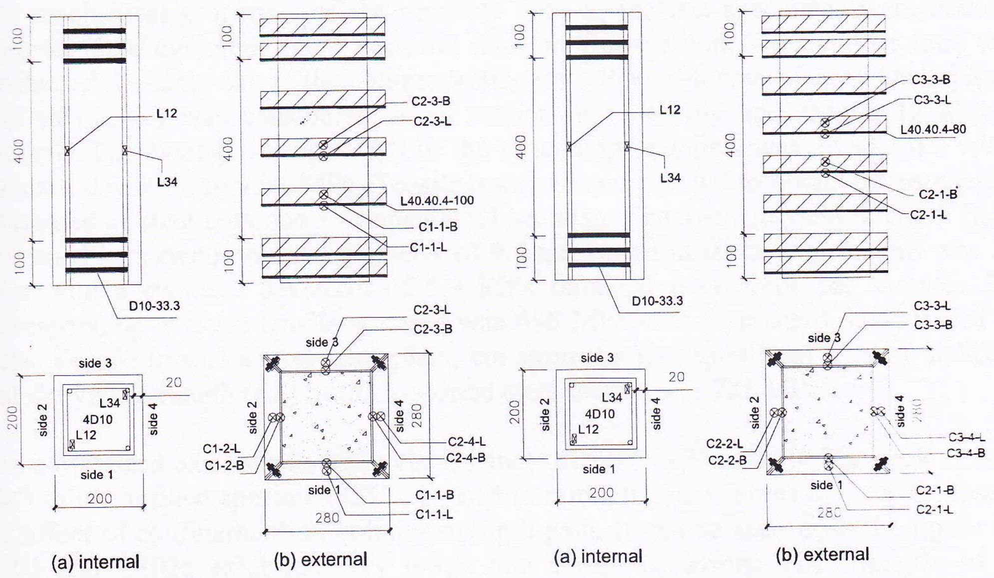



**Figure 8:** Test Specimens S03 and S04

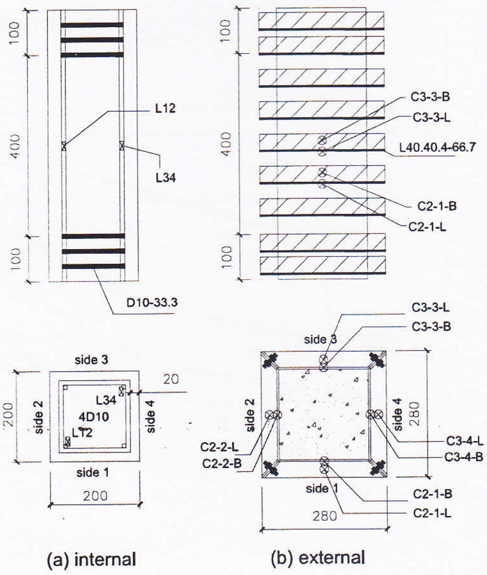



**Figure 9:** Test Specimen S05

## RESULTS AND DISCUSSIONS OF MONOTONIC COMPRESSIVE LOAD TEST

The mechanical properties of the concrete used in the test specimens were obtained from standard cylinders made from the same mix proportion. The cylinder tests were conducted the same day as the column testing (at 196 to 198 days of age). One cylinder (out of twelve) was considered as an outlier since it only had around 12 MPa in strength. The average strength ($f_c'$) of the remaining cylinders was 23.93 MPa with a standard deviation of 2.01 MPa. Tensile tests were carried out to obtain the mechanical properties of steel bars and L-shaped steel sections. The average yield strength ($f_y$) of deformed bars (with nominal diameter of 9.5 mm) used in the test specimens was 317 MPa with a standard deviation of 5.9 MPa obtained from three bar samples. The corresponding average tensile strength was 486 MPa with a standard deviation of 3.8 MPa. Tensile test of a strip steel plate, cut from the L-shaped steel section, indicated that the yield strength ($f_{ysc}$) of the L-shaped steel section was 285 MPa.

The normalized axial stress-strain curves are presented in Figure 10. The peak strength ($f_{c0}'$) of unconfined specimen CS01 is used to normalize the curves in order to observe the effect of confinement on column strength gain. It can be seen from the figure that CS01 and CS02a exhibited very brittle and abrupt behaviors. The strengths of the columns decreased rapidly after reaching the peak stress. S01 demonstrated rather similar behavior to the former two specimens except that it performed a delayed post-peak ductility response. CS03a indicated good ductility as it finally lost the strength at approximately 10 percent of strain. S02 showed a strength gain comparable to CS03a, but it failed to mimic its ductility. S03 depicted almost similar behavior to CS03a. S04 did not express the expected result since one of the collars suffered early failure. The strength gain was evident, but it evinced relatively poor ductility. S05 performed best results of all, as it gained the highest strength so as the ductility. Important stages of the tests are summarized in Table 2. The typical damage of the steel collars and concrete specimen can be seen in Figure 11.

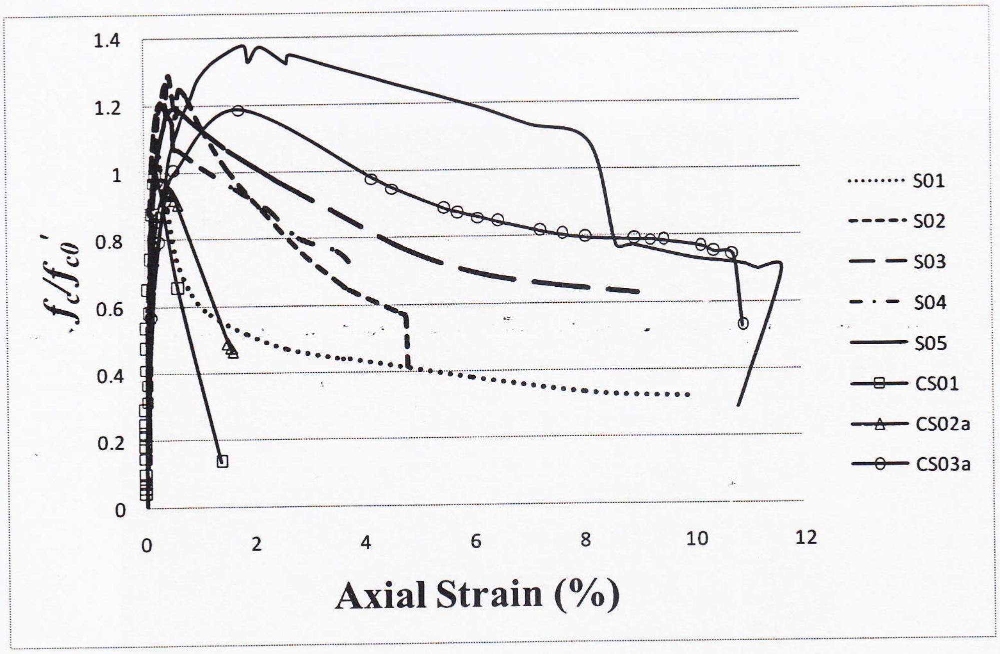
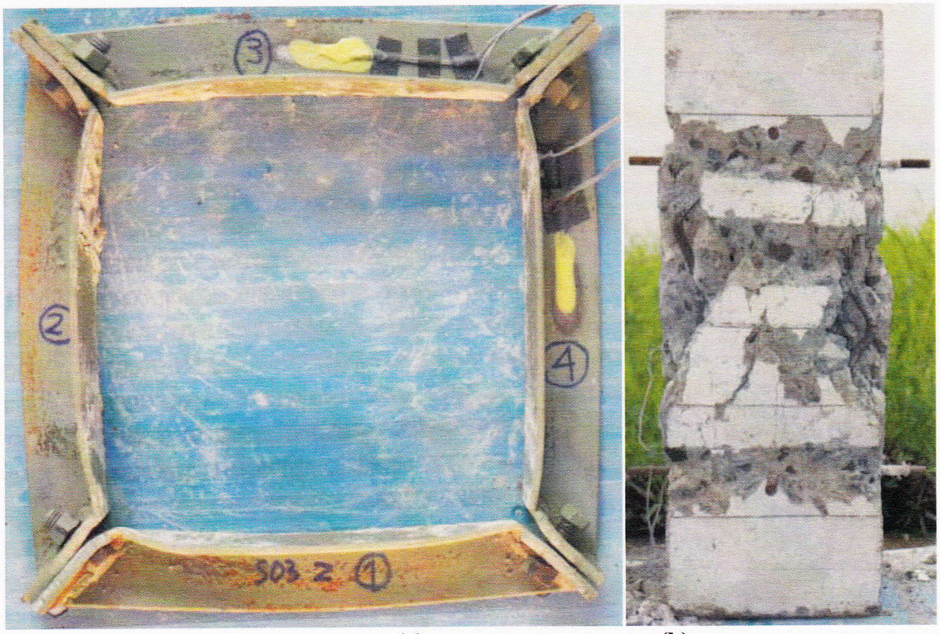



**Figure 10:** Normalized Axial Stress vs. Strain of Test Specimens

**Table 2:** Results and Important Notes on Experimental Tests of Column Specimens

| Column ID | $f'_{cc}/f'_{c0}$ | $\varepsilon'_{cc}$ (%) | $\varepsilon'_{c50}$ (%) | Important Notes and Remarks on Descending Branch |
|---|---|---|---|---|
| CS01 | 1.00 | 0.23 | N/A | Strength loss after descending branch reached up to 65 percent of peak strength (at strain of 0.61 percent). Brittle diagonal failure, buckling of longitudinal bars. |
| CS02a | 0.96 | 0.38 | 1.56 | Test was stopped after descending branch dropped below 50 percent of peak strength. Excessive damages, buckling of longitudinal bars. |
| CS03a | 1.19 | 1.75 | N/A | Test was stopped at 62 percent of peak strength (at strain of 10.73 percent) due to LVDT's maximum capacity. It could still resist higher axial load, onset of buckling of longitudinal bars. |
| S01 | 1.08 | 0.26 | 1.57 | Strength loss after descending branch degraded to 31 percent of peak strength (at strain of 8.03 percent). Brittle diagonal failure, buckling of longitudinal bars. |
| S02 | 1.29 | 0.45 | 3.74 | Strength loss after descending branch dropped to 32 percent of peak strength (at strain of 4.78 percent). Buckling of longitudinal bars. |
| S03 | 1.19 | 0.57 | N/A | Test was stopped at 53 percent of peak strength (at strain of 8.97 percent) due to LVDT's maximum capacity. It could still carry higher axial load, onset of buckling of longitudinal bars. |
| S04 | 1.21 | 0.33 | N/A | Strength loss after 58 percent of peak strength (at strain of 3.89 percent). Failure of collar 3, buckling of longitudinal bars. |
| S05 | 1.38 | 0.60 | N/A | Strength started to drop first at 78 percent of peak strength (at strain of 8.15 percent when collar 2 broken), and followed by the second drop at 51 percent of peak strength (at strain of 11.64 percent, collar 3 broken) prior to strength loss. |

Failures of collars 2 and 3, buckling of longitudinal bars.




(a) (b)

**Figure 11:** Damages of L-Shaped Collar and Test Specimen after Testing:
(a) Plan View of Damaged Collar; (b) Elevation View of Damaged Test Specimen

## CONCLUDING REMARKS

A new external confining technique to enhance the performance of square or rectangular concrete columns is proposed. The method has several advantages, such as better constructability by introducing economical L-shaped steel sections as external confining retrofit which only involves minor cutting and welding processes, and has higher applicability by only mounting up the collars on the four faces of the column without any grouting and then fasten the structural bolts at its four corners. An experimental program has been conducted to validate the reliability of the proposed technique. From the test results, some important findings can be drawn as follows:

- The L-shaped steel collars have performed as expected in the critical mid-height regions of the column specimens where damages were found most severe.
- The introduction of external confinement using L-shaped steel collars has successfully enhanced both strength and ductility of square concrete columns. The compressive strength gain was observed as high as 38 percent in the most externally-confined (collared) column specimen compared with that without confinement. With adequate external confinement volumetric ratio, brittle and abrupt failure can also be avoided.
- The externally confined regions of column specimens exhibited less damage than the unconfined column regions. This evidence proved the effectiveness of the

proposed external confinement technique. The severely damaged collars after the completion of the tests have indicated that the application of grouting between collars and column faces is no longer required in the post-peak nonlinear inelastic response since the passive confinement will have a full contact with column faces, and thus fully work at large lateral column deformation.

## FUTURE RESEARCH

The research presented herein is from the first phase of the multiyear research project conducted by the authors. In the first phase, the results of the experimental works are reported. Subsequent experimental programs in the next phases are currently designed to further investigate the feasibility of the proposed technique. A set of six specimens with various enhancements from the basic technique is prepared. Two specimens will be built to study the effectiveness of the proposed method when combined with the traditional internal confinement. The remaining four specimens have L-shaped steel collars modified by additional web stiffeners and dynabolts to enhance the stiffness of the collars. Furthermore, five column specimens (two control specimens and three collared specimens) will also be prepared to examine the performance of the proposed technique under cyclic lateral loading.

## ACKNOWLEDGEMENTS

The first phase of this multiyear research project, which included an experimental program, has been carried out in the Structural Laboratory at Center of Research and Settlement Development, Ministry of Public Works, Bandung. The authors greatly acknowledge for all the support received.

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